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A TWO-DIMENSIONAL ACOUSTIC TARGET MODEL.(U)
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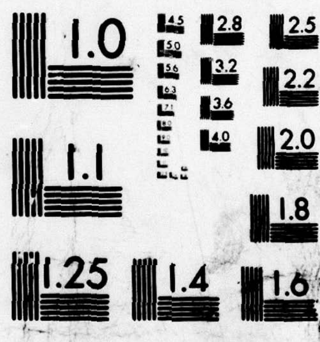

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A TWO-DIMENSIONAL ACOUSTIC TARGET MODEL

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by
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Signal Recognition Division (Code 606)

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FOREWORD

(U) This technical note describes a portion of the work being done by the Signal Recognition Division, Code 606, NURDC/SD in support of SF-11-121-106, TASK 8132 NURDC Problem Number E111. It has been prepared in the interests of others at NUC and possibly a few persons or activities outside NUC. Only limited distribution is contemplated.

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INTRODUCTION

(U) *Due to the statistical nature of the active sonar detection and classification* problem, the development of signal processing techniques for detection and classification requires an extensive data base for performance prediction. A host of restrictions make at-sea collection of the necessary data base a virtual impossibility. It is, therefore, necessary to simulate most or all of the required data base. The logical first step in the development of an active sonar echo simulation algorithm is to develop an acoustic target model. The remainder of this note documents a two-dimensional acoustic target model developed by NUC, Code 606. The actual echo simulation algorithm will be documented at a later date as an NUC TN.

THE MODEL

(U) The model consists of 30 ideal pt. reflectors randomly distributed (uniform density) throughout an ellipse with 100 yd. and 10 yd. major and minor axes, respectively. A graphic representation of the model is given in figure 1. Each ideal pt. reflector was assigned a reflection coefficient b_i

(1) $$0.1 \leq b_i \leq 1.0\ ;\ i = 1, 2, \ldots, 30$$

in pseudo-random fashion. That is, each reflector was randomly (uniform density) assigned a coefficient between 0.1 amd 1.0, with the exception of certain reflectors in the vicinity of the sail, the bow, and the stern. These reflectors were randomly (uniform density) assigned coefficients between 0.5 and 1.0 to emphasize the sail as a major reflector and to emphasize the length-to-width ratio of the target.

(U) Thus far the model is described by the 90 parameters

(2) $$r_i, \theta_i, b_i\ ;\ i = 1, 2, \ldots, 30$$

listed in table 1: where r_i is the distance to the i^{th} reflector from a center of rotation fixed on the sail 100 ft. back from the bow; and θ_i is the angle, measured in the counterclockwise direction, made by r_i with a coordinate system (x, y) which is fixed to the target center of rotation and has the bow in the negative y direction.

(U) To inject some measure of realism into the model, the following scheme for aspect dependent shading was adopted. First the position of each reflector is expressed relative to a coordinate system (x', y') whose negative y' axis is in the zero aspect direction. The reflectors are then arranged in ascending order of $y'_j(\phi)$; $j = 1, 2, \ldots, 30$ for a given aspect angle ϕ. The quantities

(3) $$\Delta x'_{ij}(\phi) = \left| x'_j(\phi) - x'_i(\phi) \right| ; \quad \begin{array}{l} j = 1, 2, \ldots, 30 \\ i = j + 1, \ldots, 30 \end{array}$$

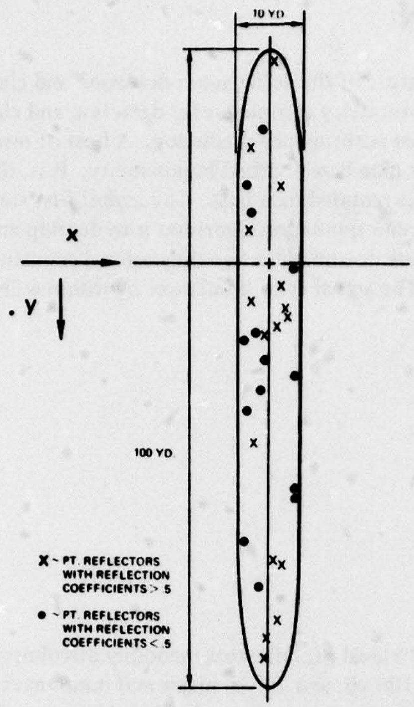

Figure 1. Two dimensional acoustic target model. (U)

TABLE 1. TARGET MODEL PARAMETERS (U)

r_i	θ_i	b_i
18.4706967548	4.87133096	.6193703842
28.4492882830	1.49042425	.7090825801
47.2238044618	1.60668811	.8096446027
55.7961852057	1.58891356	.9428588869
46.6557393922	1.57428846	.8607182313
13.2558880628	5.00713511	.2361871127
20.3428066801	1.49541281	.1917905558
63.0865386538	1.55680593	.5426598491
8.6190682061	1.87673291	.7263453388
23.5764799700	1.39608305	.1079446319
50.6148624718	1.54181413	.1432476986
8.2484561512	1.87728484	.9144455077
12.6584778300	4.53238787	.6132907199
59.2132643750	1.56710145	.8114939751
11.2749847886	1.48333792	.7813244217
6.4388827838	1.09740763	.8575322689
10.2686130044	1.66123923	.9705755853
32.7636157442	4.70926406	.8399749399
6.6626488419	5.25010556	.9486268030
4.0407719755	-2.08339489	.6712365390
35.91495736	1.68235008	.26728833

TABLE 1. (Continued) (U)

r_i	θ_i	b_i
15.25073657	1.56632738	.32053488
18.27566460	1.79966074	.14825692
4.00887939	2.93482498	.31333971
36.91767504	1.67877373	.27319979
43.11353185	1.48509491	.12978495
18.83761778	1.80058817	.12957422
11.77211125	1.42528440	.16357789
7.68013940	5.10716318	.26733749
21.41306661	4.74912856	.12092580

are then computed, and stored if

(4) $$\Delta x'_{ij}(\phi) < 1 \text{ ft.}$$

Next let

(5) $$C_{ij}(\phi) = \begin{cases} \Delta x'_{ij}(\phi) \text{ ; if } \Delta x'_{ij}(\phi) < 1 \text{ ft.} \\ 1 \quad \text{ ; if } \Delta x'_{ij}(\phi) \geqslant 1 \text{ ft.} \end{cases}$$

Finally, the new aspect dependent coefficients $C'_i(\phi)$, i = 1, 2, . . ., 30 are given by

(6) $$C'_1(\phi) = b'_1$$

and

(7) $$C'_i(\phi) = b'_i \prod_{j=1}^{(i-1)} C_{ij}(\phi) \text{ ; } i = 2, 3, \ldots, 30$$

where b'_i, i = 1, 2, . . ., 30 represent b_i, i = 1, 2, . . ., 30, rearranged in ascending order of $y'_j(\phi)$. j = 1, 2, . . ., 30.

(U) The shaded model is then completely specified by the parameter set

(8) $$r_i, \theta_i, C_i(\phi) \text{ ; } i = 1, 2, \ldots, 30$$

for a given aspect angle ϕ, where $C_i(\phi)$, i = 1, 2, . . ., 30 represent $C'_i(\phi)$, = 1, 2, . . ., 30, rearranged into the original order of the reflectors.

(U) Hence, assuming a point transmitter and receiver at the same point in space and ignoring the effects of propagation, the echo resulting from a transmitted signal S(t) is

(9) $$E(t;\phi) = \sum_{i=1}^{30} C_i(\phi)\, S[t - \frac{r_i}{C} \sin(\theta_i + \phi)]$$

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where C is the speed of sound in sea water. For

$$S(t) = \frac{\sin(157t)}{(157t)} \cos(31{,}400t) \tag{10}$$

figure 2 shows E(t) with aspect shading, and figure 3 shows E(t) without shading.

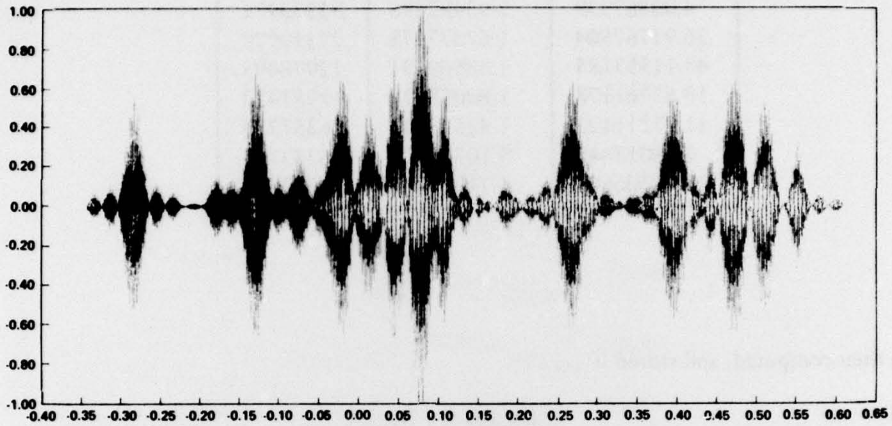

Figure 2. E(t) with aspect shading (normalized w rt highest value and sampled at 20 kHz) for $\phi = \frac{\pi}{4}$. (U)

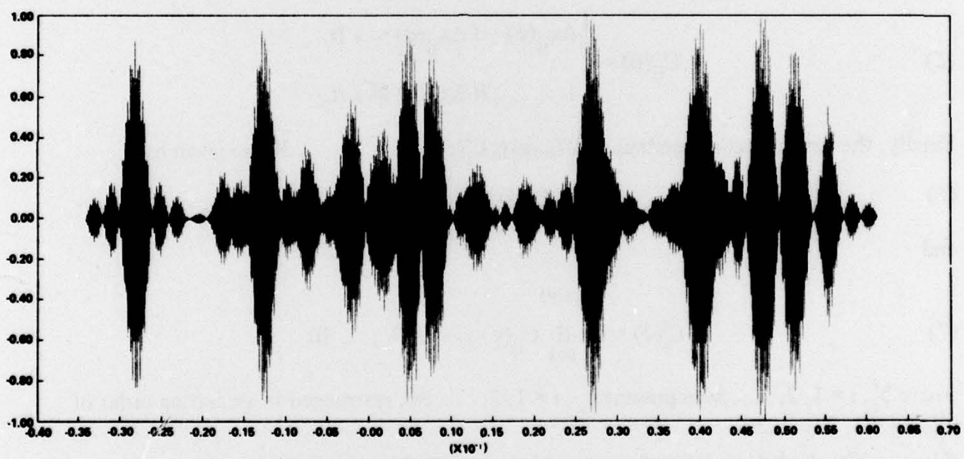

Figure 3. E(t) without aspect shading (normalized to highest value, and sampled at 20 kHz) for $\phi = \frac{\pi}{4}$. (U)

QUALIFICATION OF THE MODEL

(U) The quality of any mathematical model should, in some way, be proportional to how well it represents the physical phenomenon it is supposed to model. The standard means of measuring the acoustic-reflective properties of a submarine is to record its acoustic scattering pattern or target strength pattern. This is a circular plot of the peak echo amplitude, in dB, versus the target aspect angle ϕ. It is recorded by circling the sub at close range, transmitting a short pulse at a high repetition rate, and recording the peak echo amplitude as a function of aspect angle. Figure 4 shows a target strength pattern

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recorded for the U.S.S. Nautilus.[1] Figure 5 shows an equivalent target strength pattern for the model with aspect shading, generated from equation (9) by varying ϕ and determining

$$E_{MAX}(\phi) = \underset{t}{\mathrm{Max}} \, [E(t;\phi)] \tag{11}$$

with S(t) given by equation (10). An equivalent model target strength pattern without aspect shading is shown in figure 6.

[redacted] In comparing the aspect shaded model target strength pattern with that for the Nautilus, the difference between the target strength at beam aspect and that at bow or stern aspect is a much more important measure than fine grain structure. This is because the fine grain structure of the target strength pattern for a given submarine will vary significantly from one recording to the next. The difference between beam and bow aspect is approximately 10 dB for the Nautilus, and approximately 9 dB for the aspect shaded target model. From this result it follows that the model is a very reasonable two-dimensional acoustic representation of a submarine.

[1] "Submarine Target Strength Summary – Part X" (U), by W. J. Leiss. Penn. State University. ORL/TM 204.4611-11 (CONFIDENTIAL).

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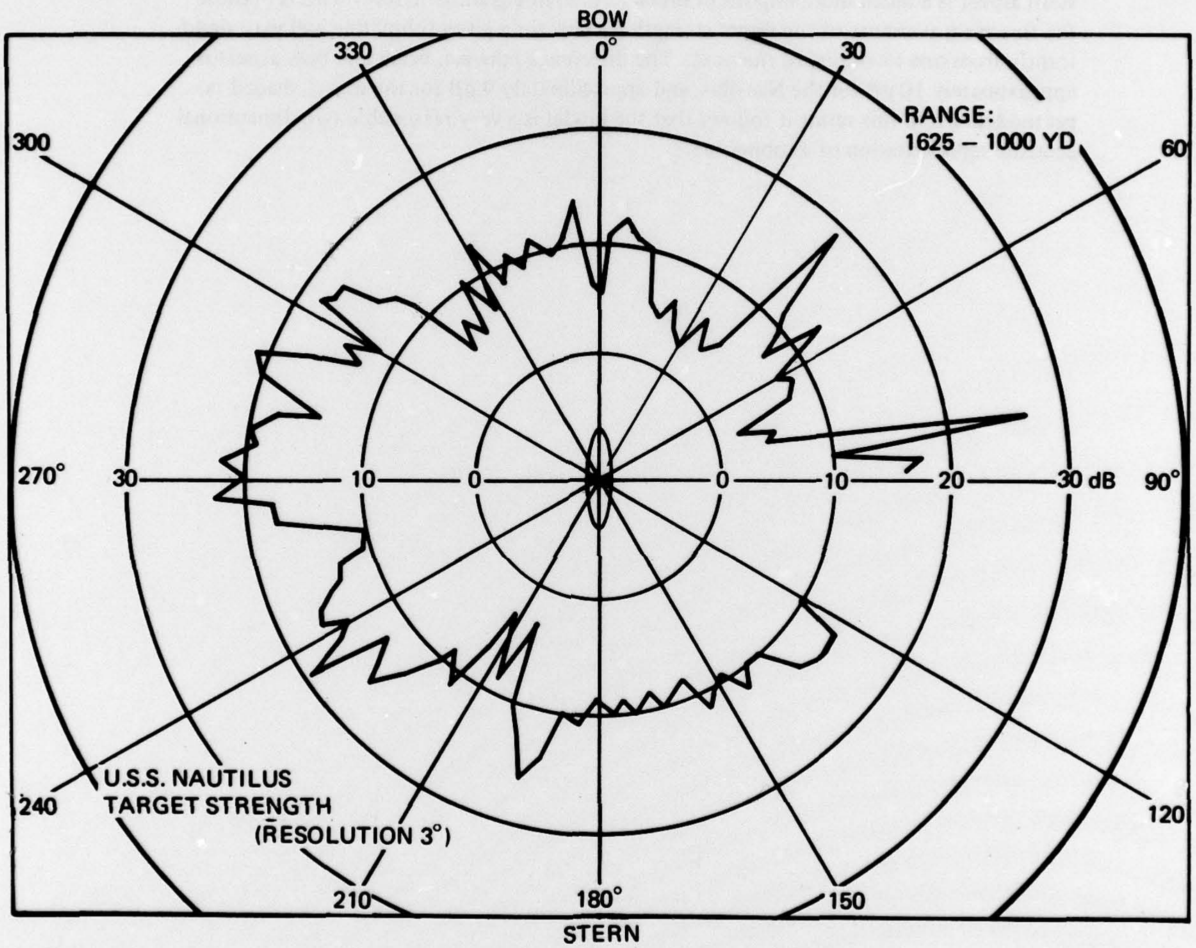

Figure 4. USS NAUTILUS target strength pattern. (C)

20.5 KHz

5 Ms Pulse

CW Tone

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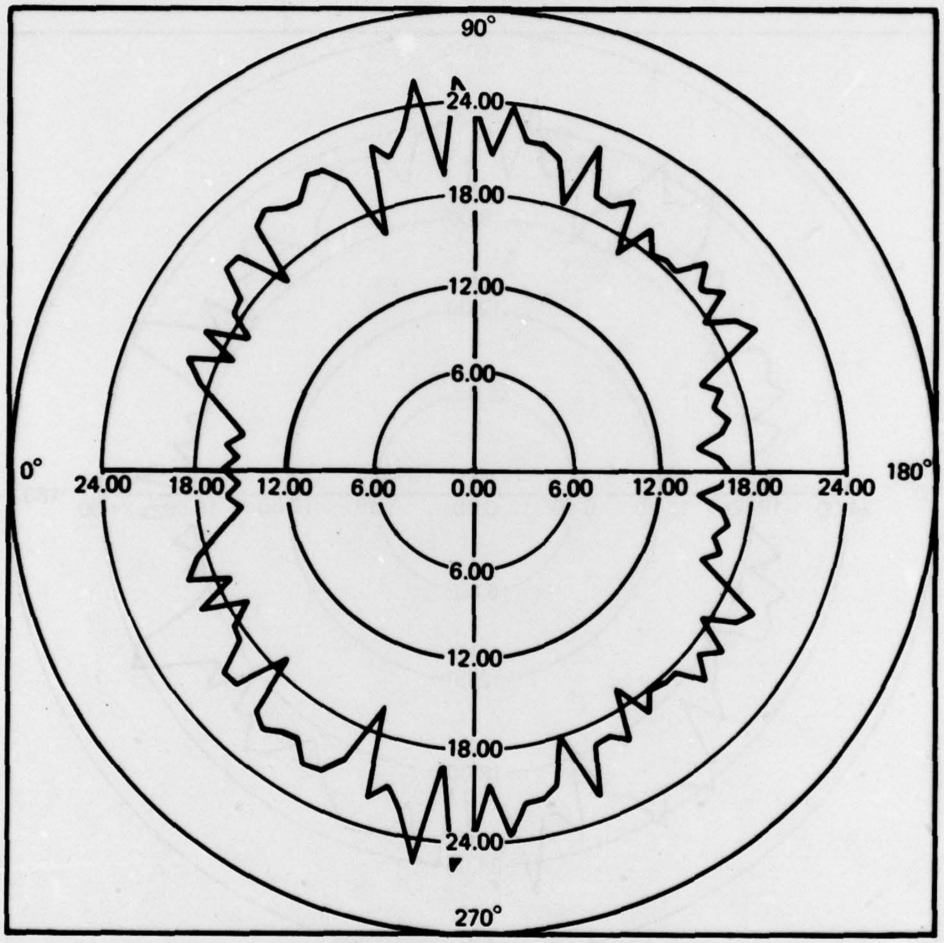

Figure 5. Shaded model target strength pattern. (U)

5 ms pulse
5 KHz

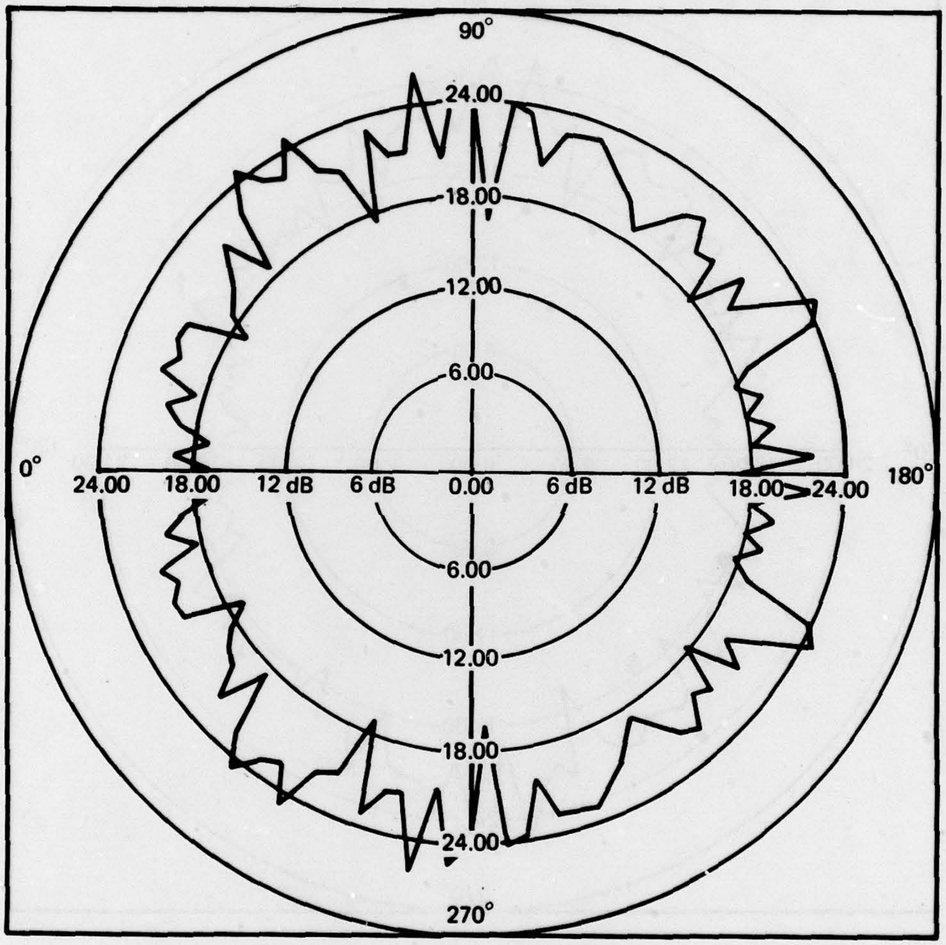

Figure 6. Unshaded model target strength pattern. (U)